A NEW SELF-REGISTERING TRANSPIRATION MACHINE.

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TRANSPIRATION is so important and conspicuous a function of ordinary land plants that the number of papers dealing with it, as a whole or in part, sufficed already a decade ago to justify the compilation of "the materials for a monograph." No contributor to this literature can have failed to feel the need of some device by which he could record the plant's loss of water, with such ease and accuracy as various auxanometers, for instance, make possible for its growth. Several contrivances for this work have been described, and a few have been put to actual use by their inventors; but none has as yet been well enough adapted to the purpose to bring it into general use, or make it any standard part of laboratory equipment.

Pfeffer[1] refers for such apparatus to papers by Vesque, Eder, Krutizky, Marey, and Anderson. Eder[2] measured only the absorption of water. A tracer fastened to a cork floating in a burette from which the water is drawn makes the absorption self-registering. The apparatus used for investigation by Vesque[3] was not self-registering, but was simply a glass siphon with the shoot being tested in one end, and filled to a given point in the other arm with water, and weighed; after a time it was reweighed, showing the weight of water transpired, and filled to the original level and weighed, showing the weight absorbed. Absorption and transpiration are not necessarily equivalent, for any given time-interval. Krutizky's[4] apparatus consisted of a siphon into

[1] Pflanzenphysiologie 1 : 224. 1897. [Ed. 2.]

[2] Untersuchungen über die Ausscheidung von Wasserdampf bei den Pflanzen 106. Leipzig. 1875.

[3] L'absorption comparée directement a la transpiration. Ann. Sci. Nat. Bot., VI. 6 : 201.

[4] Beschreibung eines zur Bestimmung der von den Pflanzen aufgenommenen und verdunsteten Wassermenge dienenden Apparates. Bot. Zeit. 36 : 161.

one end of which a leaf or shoot was sealed, while the other was connected with an areometer. The water absorbed by the shoot was drawn from the areometer, which would then rise, and its rise could be recorded by a needle attached to it and traveling on a smoked cylinder. As far as I know, this apparatus has never been used at all. Pfeffer's citation of Marey is "Methode Graphique, 1st ed.," which I have not seen. In the second edition, 1885, pp. 255–258, are brief descriptions of several machines for the automatic registration of changes in weight, used in meteorology to measure rainfall, but equally adapted to use in measuring transpiration, as is illustrated by a curve obtained by Marié-Davy with one of them. Anderson's[5] plan is to collect the transpired water by means of an absorbent on a scale pan. When the balance is sufficiently disturbed, an electric circuit is closed, which drops a weight on the other pan, restores the equilibrium, and makes a record of the time.

Woods[6] has used a rain gauge to measure transpiration, the machine being set up so that the plant's loss of weight opens an electric circuit, this moves the tracing pen and also a counterweight, which closes the circuit again. A sample of the record shows the soundness of the device. Francis Darwin[7] speaks of an attempt to construct a self-registering balance by placing a spring under one pan and prolonging the knife edge as a tracer.

All of these devices except Darwin's, which was never applied to measuring transpiration, are founded on one or the other of two principles: the use of the areometer, as in the apparatus of Rédier and of Salleron, cited by Marey, and of Eder, Krutizky, and Vesque; or the imposition of counterweights at the instant demanded by the change in weight of the subject, as in the apparatus of Ragona, described by Marey, and of Anderson and Woods. They have employed both of the reliable methods of measuring the transpiration, namely, weighing the plant, and collecting and weighing the evaporated water. Eder made a

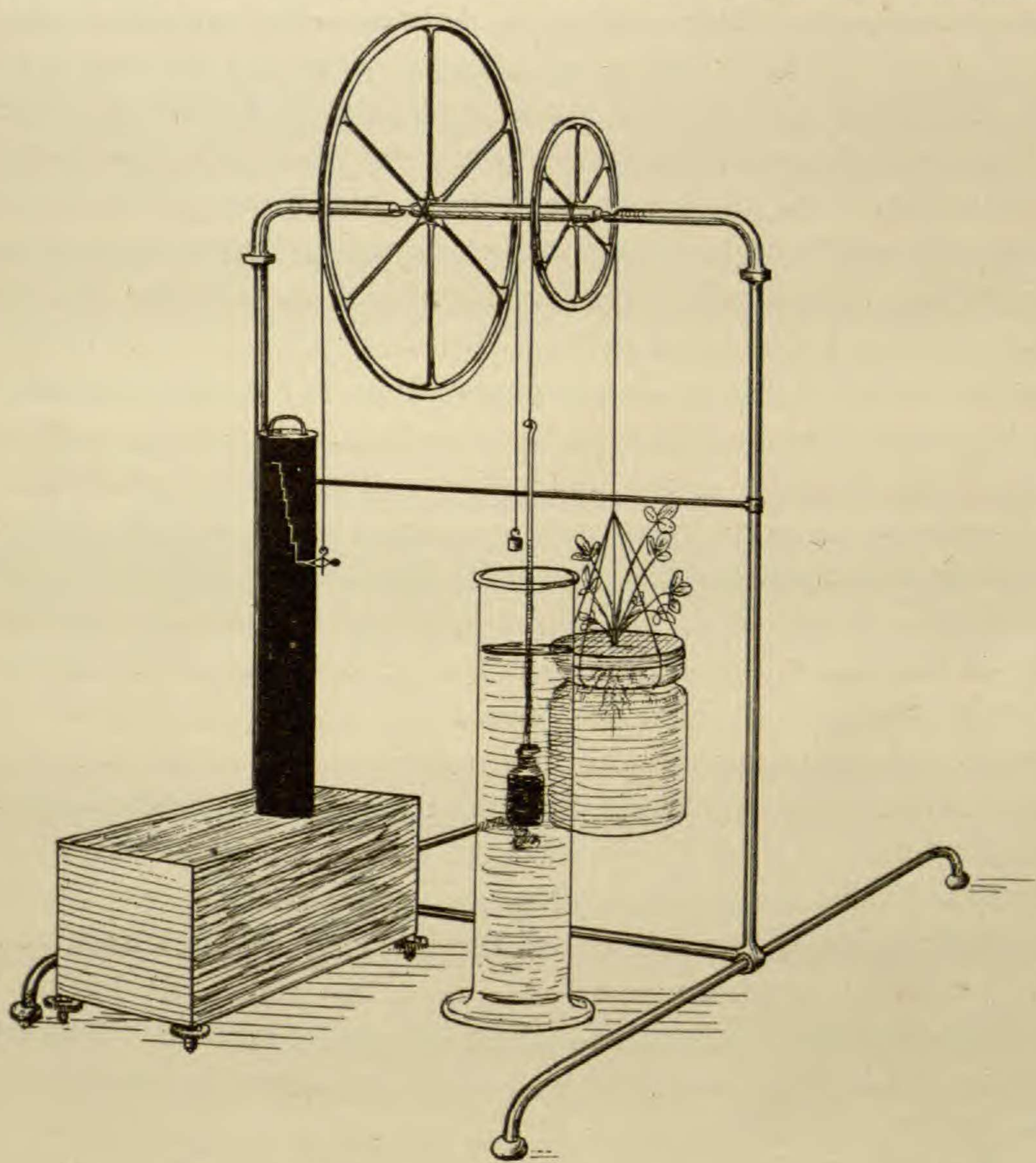
[5] Minnesota Botanical Studies 1 : 177. 1894.

[6] Recording apparatus for the study of the transpiration of plants. BOT. GAZ. 20 : 473.

[7] Annals of Bot. 7 : 461.

mistake in measuring the water absorbed, and Krutizky's apparatus is inapplicable for the same reason.

The apparatus now to be described was made for the Indiana University, from my plan, through the Cambridge Botanical



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Supply Company, by Professor J. C. Arthur. The cost is about $35. The frame, made of iron tubing, stands twenty-five inches high, and is fifteen inches wide. Each arm bears at the end a piece of plate glass, which must lie with its upper face exactly horizontal. Two wheels of aluminum, cut out so as to be as light as possible and perfectly centered, have a common axis, whose ends are slender cylinders, rolling on these plate-glass supports. The wheels are six and twelve inches in diameter, and absolutely true; when not loaded they are at rest anywhere on the supports. Over one of the wheels—the smaller one, as I have used the apparatus—runs a thread or string, which carries on one end the plant whose transpiration is to be tested. The other end is fastened to an areometer, weighted until it is partly submerged. For this areometer I use a bottle partly filled with mercury, with a tight-fitting cork, into which is sealed a glass rod or tube. It is convenient to use a tube, so that the load of mercury can be adjusted without disturbing the cork. For the string I used double heavy silk thread, boiled in beeswax, and rubbed until it would not stick to the wheel. It was fastened to the upper end of the glass tube, out of contact with liquid water, and altogether was pretty well protected against hygroscopic changes in length.

Now, as the plant transpires it becomes lighter, and the areömeter sinks, displacing exactly the mass of water at that end of the string which has been lost by evaporation at the other. If, for example, the area of a section of the tube be $1^{sq\ cm}$, it will sink 1^{cm} while the plant loses 1^{g} in weight. The larger wheel carries a thread, with a tracer which leaves its record in the same way as that of an auxanometer.

What are the limitations of the working of the machine? When it is used with proper care, there is practically but one, the inertia of the resting load which the wheel carries. Friction is practically eliminated. The axis turns more easily than would be feasible on ball bearings. The only remaining obstacle to perfect ease of movement is the surface tension of the water; but the capillarity is not very considerable even at its theoretical maximum, which is never reached, and if the tube is uniform and clean it will hardly vary as the tube descends. Jars and irregular drafts must of course be avoided.

It has been possible to put the apparatus to an unfortunately brief test. Both potted plants and water cultures were used;

the latter are rather more convenient since there is only the top of the containing vessel from which evaporation must be prevented. Several attempts were necessary before a large enough tube was used on the float; *i. e.*, the apparatus was at first set up so as to be too sensitive. A slender tube is appropriate when the intervals of time are short; but it sank so fast that it reached bottom within a few hours. The results introduced below were obtained by the use of a tube whose cross section was $\frac{5}{8}^{\text{sq cm}}$; one, therefore, which would sink 8^{cm} while the plant lost 5^{g}. in weight. As the areometer sank, the water it floated in rose a very little, but this is not a source of error because the water was in the same vessel when the value of a unit of movement was determined. I did not guard against evaporation from this water, as would be advisable if the clover plant instead of the apparatus were the real subject of experiment. For the same reason, the temperature and relative humidity do not concern us here. The plant was a red clover with about ten leaves, grown in soil, but transferred to water two days before the experiment began.

The data are derived from an experiment on June 15 and 16, and are given in measurements of vertical distances on the smoked cylinder, and in grams of water. Hours in light-face figures are A.M., those in bold-face figures P.M.:

Hour	Record in mm.	Weight in gm.	Hour	Record in mm.	Weight in gm.
9–10	25.6	0.800	1–2	2.9	0.091
10–11	20.3	0.635	2–3	3.7	0.116
11–12	14.6	0.456	3–4	3.5	0.109
12–1	22.3	0.697	4–5	3.9	0.122
1–2	29.5	0.922	5–6	4.6	0.144
2–3	4.0	0.125	6–7	14.2	0.444
3–4	3.8	0.119	7–8	22.9	6.716
4–5	4.0	0.125	8–9	26.6	0.831
5–6	5.9	0.184	9–10	31.1	0.972
6–7	4.2	0.131	10–11	23.0	0.719
7–8	3.9	0.122	11–12	9.9	0.309
8–9	3.7	0.116	**12–1**	8.7	0.272
9–10	3.0	0.094	**1–2**	11.9	0.372
10–11	2.7	0.084	**2–4**	15.2	0.473
11–12	2.3	0.072	**4–5**	6.3	0.197
12–1	3.0	0.094	**5–6**	5.5	0.172

In measuring the distances registered on the smoked cylinder I attempted accuracy to 0.1^{mm}, which is rather finer than is safe. I believe that the real limit to the accuracy of the results to be obtained with this apparatus lies in our ability to measure the trace. The weight on each side of the wheel in this test was only about 700^{gm}, less than would often occur in practical use. It has not been practicable to make a test with a greater load than 3.5^{kg}, with which, under proper conditions, it responds to a change of not more than 50^{mg} in either direction.

It is a merit of this apparatus that it will register equally well a decrease or an increase in weight, without any change in the setting up, except as the areometer will be set deep in the water if a continued increase is anticipated. It can be used to measure the changes in weight of fruits, etc.; and with some modification in details, the plan of the experiment is a good one for delicate and accurate measurements of the pressure of growing roots, the lifting power of prostrated grass stems, etc.

Finally, one comment on the table, introduced only as an illustration, a further discussion being reserved for a future time: the remarkable transpiratory activity during a few hours of both forenoons is not an error, nor does it seem to be an accident; for four different plants of red clover showed the same striking behavior.

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